InSight

16th International Planetary Probe Workshop

INSIGHT APPROACH OPERATIONS DURING DUST-STORM SEASON

Eugene P. Bonfiglio, Devin Kipp, and Evgeniy Sklyanskiy
Jet Propulsion Laboratory, California Institute of Technology

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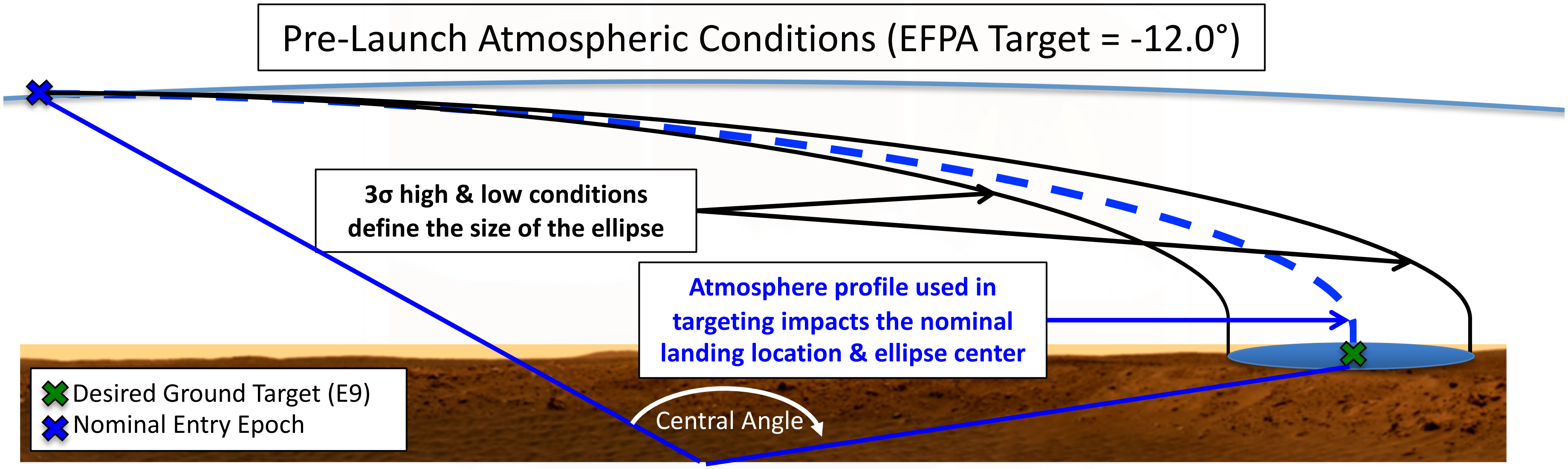
Introduction

- NSYT discovered that small updates in atmosphere knowledge, based on real-time MRO measurements, can cause large, unexpected fluctuations in the final trajectory correction maneuver (TCM) that targets the desired entry conditions
- Operational planning and accommodation of this issue is exacerbated by landing during dust storm season
- We'll discuss the causes and impacts to requirements and EDL operations plan as a result of this atmosphere dependency
- Also touch on other ways in which the EDL operations plan was impacted by dust storm season

Simplified Explanation of Maneuver Targeting Process

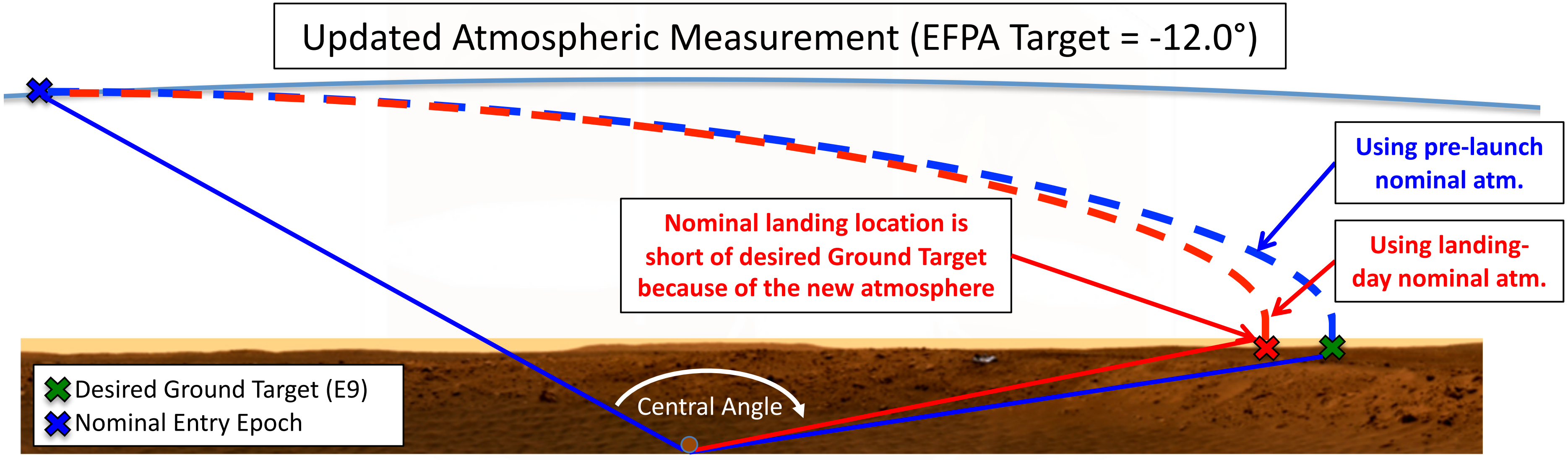
- Navigation designs a maneuver that targets the desired Ground Target with a specific Entry Flight Path Angle (EFPA) Target through an iterative process
    1. The nominal trajectory is integrated and the nominal landing location is compared to the desired Ground Target
    2. The entry epoch is adjusted so the nominal landing location of the nominal trajectory will hit the desired Ground Target
    3. Steps 1 & 2 are repeated until we hit the Ground Target at step 1



For a fixed EFPA, the arc flown through the atmosphere (central angle) is always the same

Impacts of Updating the Atmosphere

- Atmosphere measurements from MRO are used to update the atmosphere model prior to EDL
- Updating the atmosphere model changes the central angle of the nominal trajectory and *directly impacts the targeting scheme*
  - Changes to the nominal trajectory shifts the nominal landing location



Shift can easily be 10 km or more (in the case of a dust storm)

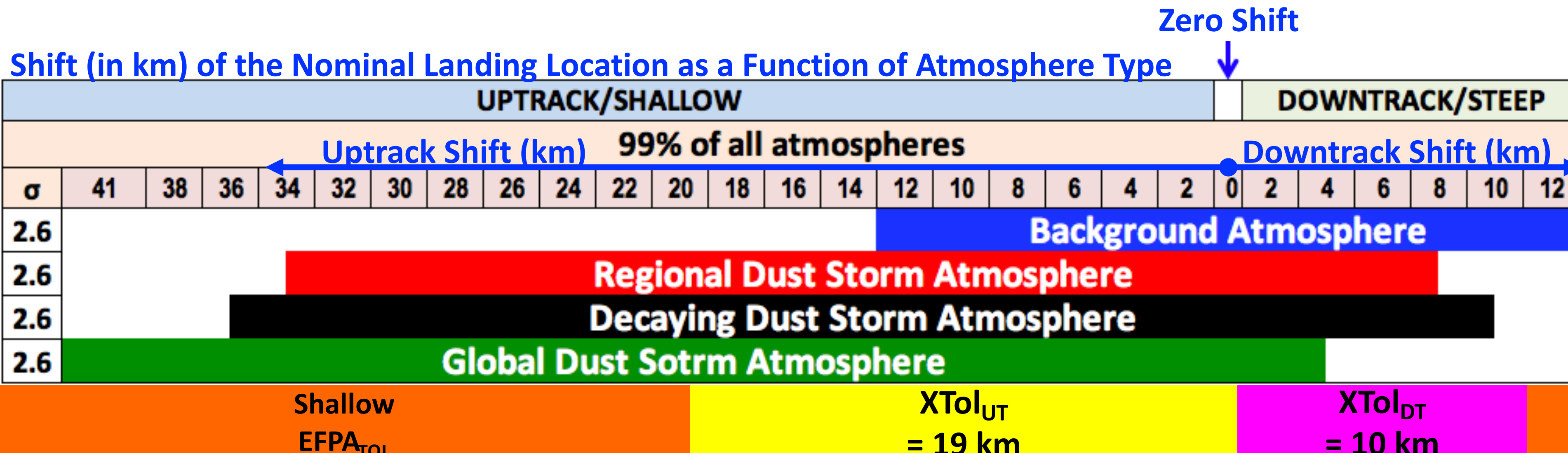
Options for Accommodating Atmosphere Changes

- Option 1: Allow Entry Epoch to Vary
  - Does not restore the central angle
  - Changing the entry time at final TCM is propulsively expensive
- Option 2: Allow Ground Target to Move (Ground Target Tolerance)
  - Does not restore the central angle
  - Zero ΔV cost
    - Essentially ignores the atmospheric update and allows the nominal trajectory to land wherever the new atmosphere puts us on the ground
  - Negative impacts to landing site selection (increases the required size of acceptable area)
- Option 3: Allow Entry Flight Path Angle to Vary (EFPA Target Tolerance)
  - *Does* restore the central angle (entry epoch *and* ground target unchanged)
  - Very minimal ΔV impact (<5 cm/s at final TCM)
  - Modifying the EFPA target changes the carefully-chosen balance of margins

NSYT Targeting Strategy to Account for Atmospheric Updates

- InSight defined separate ground target tolerances in the downtrack/clear ($Xtol_{DT}$ = 10 km) and in the uptrack/dusty directions ($Xtol_{UT}$ = 19 km)
- The team also used an EFPA target tolerance ($EFPA_{TOL}$) of ±0.15° about the desired nominal EFPA (-12.0°)
- The EDL-Nav team assesses the new atmosphere and…
  - Uses the ground target tolerance first to define a new ground target
  - In extreme cases we will use both ground target and EFPA target tolerances (i.e. Nav would target an EFPA between -11.85° and -12.15°)

Shift (in km) of the Nominal Landing Location as a Function of Atmosphere Type



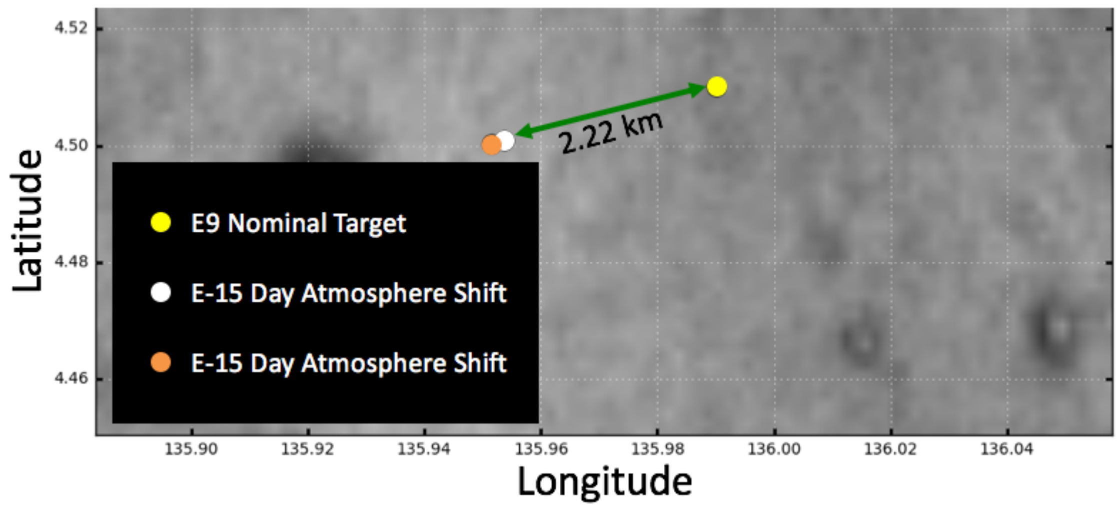
InSight Maneuver strategy accommodates 99% worst-case Global Dust Storm

InSight Operations

- Actual landing day measurements were pretty benign compared to worst-case scenarios

- Shifts were on the order of 2-3 km

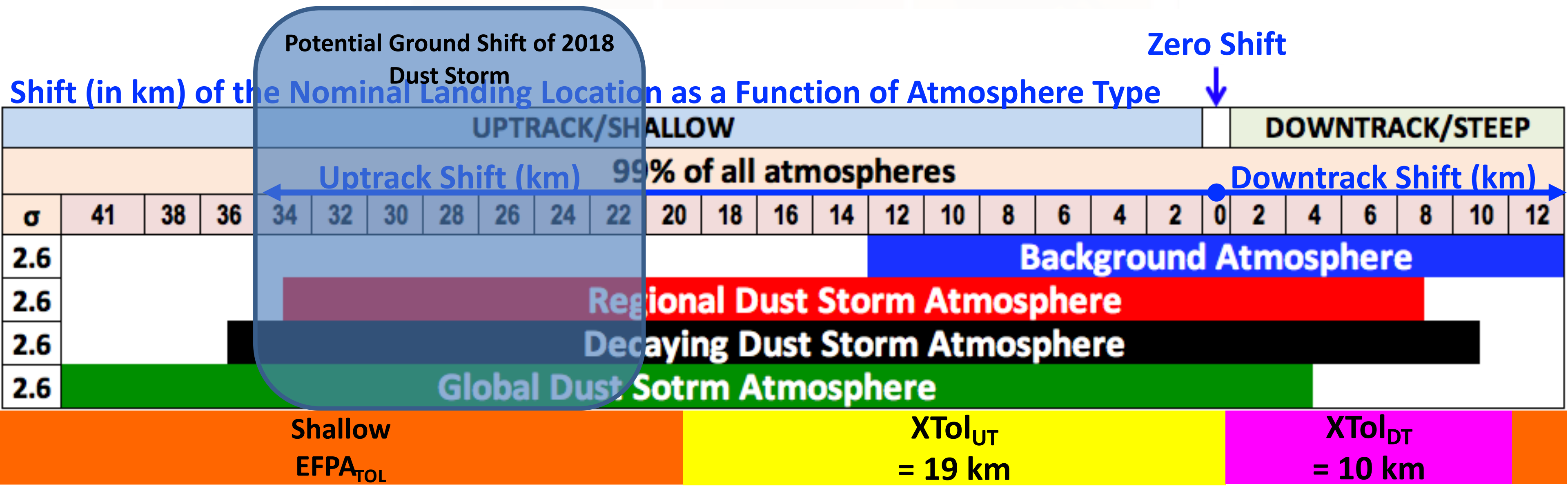
Atmosphere Model	Ground Shift Relative to E9 Landing Target	Shift Direction	Date Released
Background	0 km	N/A	Pre-Launch
E15	2.22 km	Uptrack	11/12/18
E7	2.35 km	Uptrack	11/20/18



But what if the 2018 Mars global dust storm occurred closer to our landing epoch???

2018 Martian Global Dust Storm

- A global dust storm began on Mars in June 2018 and subsided by October 2018 (1 month prior to EDL)
- Had the storm started a few months later, the plan for dealing with atmospheric changes would have had a much greater impact to operations
- Best guesses are the shift would have been in the 20-35 km range
  - Ground target would have shifted by 19 km and EFPA target would have been close to -11.95° To -11.9°.



Other Dust-Storm Season Impacts to EDL Operations

- Parachute deploy conditions varied significantly depending on dust conditions present at entry

- EDL parameters updates of the deploy trigger needed to:
  - Account for a potentially dynamic dust-condition
  - Yet be simple enough to not require time-consuming real-time Monte Carlo analysis to properly tune the trigger

- Dependencies existed between parachute deploy altitude and potentially dangerous radar idiosyncrasies
  - Large range in deploy altitude for various dust conditions required a more intelligent timer for when to start searching for the ground
  - More complex tuning of the radar initialization timer during operations

Conclusions

- The targeting complexity is a real issue for any lander that updates their atmosphere based on real-time measurements, and which doesn't have guidance.
  - Even if you ignore the affect in targeting, the bias will show up in the placement of the landing ellipse.

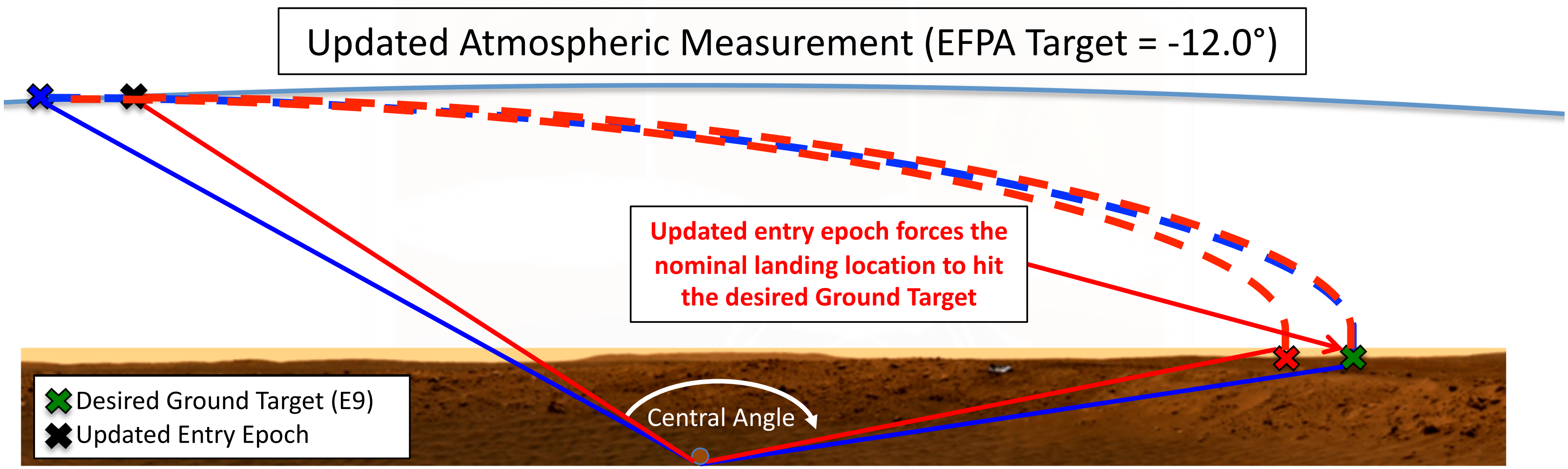
- EDL missions that plan to use real-time atmosphere measurements to assess EDL performance should understand the influence to operations
  - Real-time testing to understand hidden dependencies are necessary
  - Make sure requirements are written to accommodate these impacts.

- Without a plan to address this issue, the InSight project would have been taken by surprise had the 2018 global dust storm intersected with our arrival at Mars.

Backup

Option 1: Allow Entry Epoch to Vary

- Does not restore the central angle
- Changing the entry time at final TCM is expensive
  - Increases TCM-6 ΔV well beyond our current 99% (as much as 5-10 times larger)
  - The increase would result in a much larger landing ellipse than LSS had planned for
  - Entry time change is very sensitive to miss distance on the ground (bad for EDL Comm)

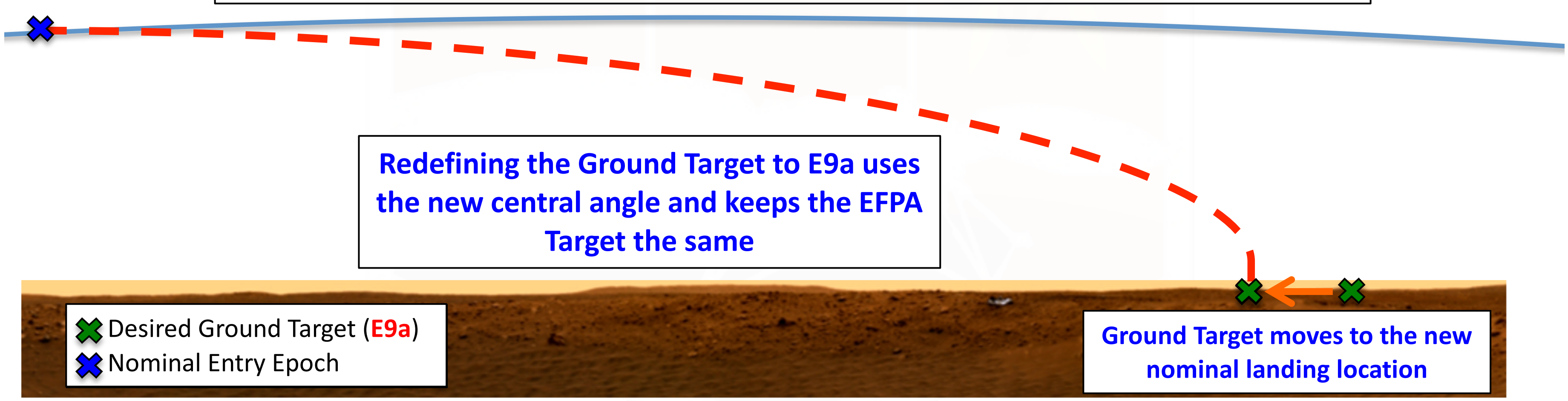


Option 2: Allow Ground Target to Move

Ground Target Tolerance

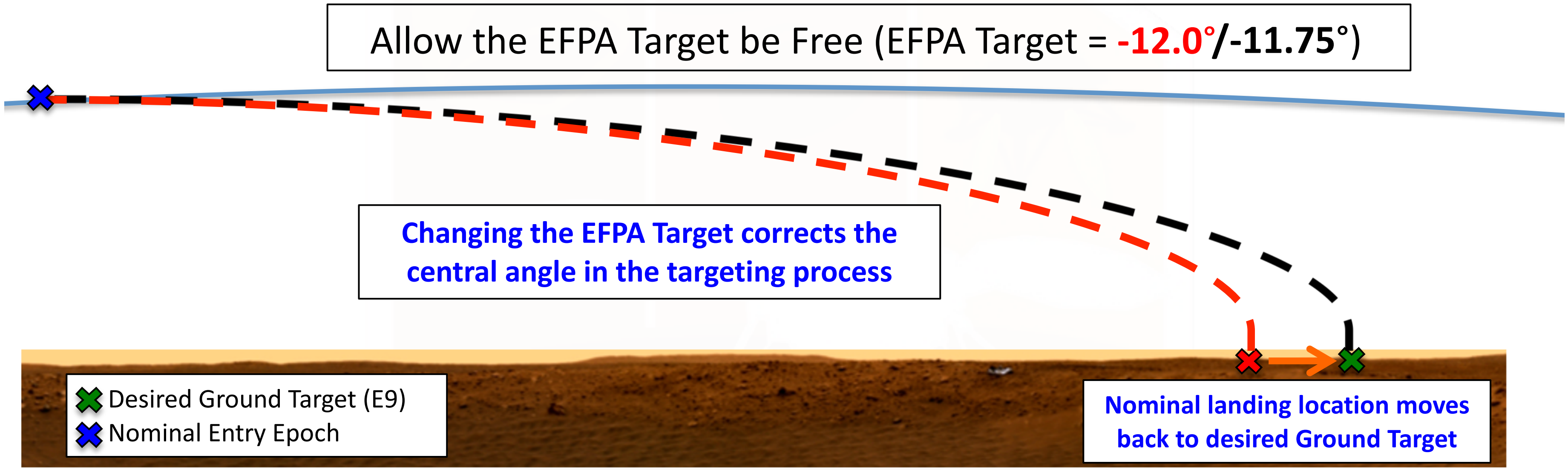
- Does not restore the central angle
- Zero ΔV cost
  - Essentially ignores the atmospheric update and allows the nominal trajectory land wherever the new atmosphere puts us on the ground
- Negative impacts to landing site selection (increases the required size of acceptable area)

Allow the Ground Target to be Free (EFPA Target = **-12.0°**)



EFPA Target Tolerance

- *Does* restore the central angle (entry epoch *and* ground target unchanged)
- Very minimal ΔV impact (<5 cm/s at final TCM)
- Modifying the EFPA target changes the carefully-chosen balance of margins



InSight opted to used EFPA and ground target tolerance to minimize costly changes to the entry epoch